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Reading comprehension in L1 and L2: An integrative approach

Ping Li*, Roy B. Clariana

Pennsylvania State University, United States

ABSTRACT

Like other areas of research in reading and language, the study of reading comprehension has traditionally focused on readers of native or first language, and relatively little attention has been directed to the study of second language reading comprehension. Even fewer studies have examined the neurocognitive bases of second language reading comprehension. In this article we take these research gaps as a starting point for providing an integrative analysis of reading comprehension in first and second languages, and with a perspective on both cognitive and neuorimaging evidence. We further examine variables of learner abilities (e.g., working memory), second language proficiency, and order of presentation/reading in the two languages that impact individual differences in reading comprehension, with a particular focus on the knowledge structure that the reader establishes in the first and second languages. Implications and future directions for an integrative neurocognitive perspective on L1 and L2 reading comprehension are discussed in light of limited evidence based on individual difference studies.

1. Introduction

Reading is a critical life skill that every citizen in our globalized world should acquire. A large amount of work in the neurocognitive literature has examined literacy development and reading disability, but this work has been primarily conducted at the single word level (see reviews in Frost et al., 2008, Gabrieli, 2009 for example). Thus, while significant progress has been made concerning the cognitive and neural mechanisms underlying single word reading and processing in a typical adult native speaker, our understanding of even sentence-level reading (Perfetti & Stafura, 2014), much less text-level reading, remains rather limited. This is especially true of reading comprehension in one's non-native language. This article is devoted to addressing this knowledge gap. We present an integrative approach toward reading comprehension (or “text comprehension”) in both the first (L1) and the second (L2) language context from a neuro-cognitive perspective.

A perennial issue in word-level literacy is how the reader can automatically map the character strings from print to the underlying meaning of the word, and what hurdles there might be in orthographic decoding, phonological encoding, and semantic integration. By contrast, the key problem we consider in text-level reading is that of mental representation of the words and associations between words, when the goal of the reader is not to just map individual word forms to lexical meaning, but to integrate interconnected words into a structured representation of the concepts being understood (i.e., building a ‘situation model’; van Dijk & Kintsch, 1983). In particular, the reader needs to establish a relational, topical, or even hierarchical organization of the critical idea/concept units that the author or writer has intended in the text, rather than arrive at no more than a collection of loosely linked concepts or terms as their mental representation. The construction of an appropriate representation of the text is an indicator of, and key to, successful reading comprehension (Fesel, Segers, Verhoeven, & Clariana, 2015; Kim & Clariana, 2015, 2017), and should therefore be a major goal for any competent reader in our society.

* Corresponding author.
E-mail address: pul8@psu.edu (P. Li).

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1.1. The Reading Systems Framework

The perspective on reading comprehension as a ‘situation model’-building rather than a form-to-meaning mapping process does not suggest that word-level reading is not important in reading comprehension. To the contrary, the degree to which readers can successfully integrate word meanings into connected conceptual units is critical for skilled reading comprehension. A useful vantage point for discussion in this regard is the Reading Systems Framework (RSF) of Perfetti and Stafura (2014), which provides a recent synthesis of the processes of word-to-text integration. The RSF approach considers reading comprehension in a dynamic framework in which multiple systems and components interact (see Fig. 1 of Perfetti & Stafura, 2014). In particular, the RSF has three key assumptions: (1) reading involves various sources of knowledge, from orthographic knowledge to linguistic knowledge to general world knowledge; (2) reading involves cognitive processes, from word identification to meaning retrieval to inference making; and (3) the cognitive processes take place within an interactive processing system that engages limited resources in attention, memory, and control. A number of studies in the literature have also explored the neurobiological mechanisms underlying these processes in the past (see further discussions below).

Central to the RSF framework, according to Perfetti and Stafura, is the lexicon, which mediates the interaction between orthography and meaning (word identification system), and the process of using the output from word identification to build meaningful conceptual representations (comprehension system). The RSF considers the reader's lexical knowledge as a prime candidate for predicting successes or failures in reading comprehension: lexical knowledge may be more important for reading comprehension, for both children and adults, than listening comprehension because of the critical role it plays in the word-to-text integration process. Indeed, there is some neural evidence that vocabulary size may serve as a general index of reading experience, reflected as decreased activity in the right hemisphere (Prat, Mason, & Just, 2010). While this perspective has significant implications for our understanding of individual differences in reading comprehension, how the word-to-text integration process interacts with other processes, such as inference drawing and situation model updating, remains to be understood at the cognitive and the neural level.

1.2. Structure and the Analysis of Lexical Aggregates

From a different vantage point, once the reading comprehension process itself is completed, the question is what new knowledge in addition to the knowledge sources as discussed by Perfetti and Stafura (2014) has the reader retained in long-term memory as a result of a successful comprehension process. And more specifically, how can it be measured? New knowledge pieces attained from reading can be elicited and represented as ‘knowledge structure’ (KS, a theory-neutral term, Clariana, 2010a). Our KS approach is an application of Jonassen, Beissner, and Yacci's (1993) conception of “structural knowledge” that purports to measure the associations among the key units of information in the text. KS is usually represented as a network graph (with concepts as nodes and relations as links) that allows quick visual and statistical comparison with other knowledge structure graphs. For example, KS can be elicited both before and after reading as a way to represent and compare change in memory for an individual in terms of continuance of prior KS and integration of the text KS (e.g., new knowledge). Ferstl and Kintsch (1999) may have been the first to measure KS both before and after undergraduate students read a 600-word “Birthday” story using a list-cued, partially-free recall approach. They established that the approach was appropriate for assessing background knowledge before reading and updates of text memory after reading. Their KS data facilitated interpretation by depicting how reading the story ‘added to’ the post-reading situation model (see Ferstl & Kintsch, 1999, Fig. 10.4) and provided another way to think about reading comprehension.

Although KS measures are usually about the reader's understanding, texts also have structures that can be captured, for example, by using tools such as Text Model Inspection Trace of Concepts and Relations (T-MITOCAR; Pirnay-Dummer & Ifenthaler, 2010) and Analysis of Lexical Aggregates (*ALA-Reader*, Clariana, 2010b). These measures of KS provide a means for more explicitly mapping the influence of reading a text on new knowledge by comparing the text KS to the readers' KS (Clariana, 2010b; Kim, 2012).

Given the above perspectives on word-to-text integration and text comprehension, a number of significant gaps exist. First, if native language speakers vary in their ability to successfully integrate words into text comprehension, as suggested by Perfetti and Stafura (2014) and Verhoeven and Perfetti (2011), we could hypothesize that vocabulary knowledge in a second language (L2) in the same way will significantly impact how well a reader succeeds in reading comprehension when the text is presented in the L2. This vocabulary knowledge may be measured as the size of the L2 lexicon, the quality of L2 semantic representations, and the speed with which L2 words may be retrieved from the mental lexicon (all three are directly related to apposite KS). Thus, one could predict that L2 proficiency, especially in vocabulary, could be a good indicator of the L2 learner's text reading performance. Currently, we have very little knowledge of the underlying neurocognitive processes that account for reading comprehension by L1 and L2 readers, because of (a) the focus on word-level processes and mechanisms and (b) the coarse temporal resolution of neuroimaging methods such as fMRI, which is too slow to capture single word processing during naturalistic reading, and therefore is also less informative on the interaction of single word processes with the construction of text-level representations and executive function.

1.3. Individual differences in executive functioning

In addition to the above considerations, there is a significant amount of individual difference in reading comprehension that can be accounted for by the reader's cognitive executive abilities, especially working memory abilities, in both children and adults (see discussion in sections 2 and 3). The relationship between reading comprehension and executive abilities is obviously also modulated by other factors, such as age (children vs. adults), internal cohesion of the text (i.e., writing quality), and type of text (i.e., narrative vs. expository). For example, expository texts such as scientific text that use unfamiliar technical vocabulary (or familiar vocabulary but with technical, unfamiliar, meanings) may place higher cognitive demands on the reader's executive functions. Eason, Goldberg, Young, Geist, and Cutting (2012) demonstrated that understanding expository texts, compared to narrative texts, requires greater ability in synthesizing information across larger chunks of text for mental organization (i.e., abilities to organize information and make inference subsequently). Buchweitz, Mason, Meschyan, Keller, and Just (2014) showed that the cognitive control network including key brain areas in the prefrontal and parietal cortex are engaged when the reader processes texts that are either unfamiliar (as compared with familiar texts) or are presented in faster-than-normal speed (as compared with normal speed). The interactions among type of text and individual differences in executive function are not well understood, which is surprising in light of our knowledge of how executive function (e.g., working memory) affects vocabulary learning and language representation in general (Baddeley, 2003b; Baddeley, Gathercole, & Papagno, 1998). A key issue here is to understand what neurocognitive mechanisms underlie individual differences, specifically how existing knowledge structure interacts with executive function differences during reading to influence the reader's KS representations after reading.

The measured KS obtained after reading narrative and expository texts are very different (Clariana, Wolfe, & Kim, 2014), and so previous neurocognitive research with narrative text cannot automatically generalize to reading a scientific expository text. More to the point, narrative and expository texts should exhibit strikingly different neurocognitive signatures since very different phenomena are involved in each. For example, brain regions and patterns of neural activation when reading narrative text should align with the narrative features of place, time, goal, characters, and causality, In contrast, expository texts place little emphasis on time-and-place context features (p.603, Clariana et al., 2014) but do depend on structural and cohesion markers (i.e., which, that, because) and also on the quality and extent of the mental lexicon (RSF; Perfetti & Stafura, 2014), and so we concur with and extend the RSF model that the individuals' *local structure of their lexicon* is the main mediating factor in expository text comprehension. Individuals with a richer and more fully structured lexicon have greater capacity to form bridging inferences with cohesive and also less cohesive expository texts.

1.4. *An integrative approach*

Although there is an emerging literature on the neurocognitive mechanisms of text comprehension (see Ferstl, 2010 and Mason & Just, 2013 for reviews), the studies so far have focused on identifying individual brain regions that are responsible for individual components involved in reading (e.g., detecting story line shifts). An important recent movement in cognitive brain research is the study of brain networks through the connectivity that exists in the functional and structural pathways of the learning brain. Though computationally challenging, this brain network approach holds the promise of providing new insights into the neural bases of individual differences, neuroplasticity, and L1 and L2 learning and representation (see Sporns, 2011). Many types of data analytics may be applied to the study of brain networks to probe into the dynamic changes in connectivity patterns, including graph-theoretical models (Power, Fair, Schlaggar, & Petersen, 2010). With this approach, we can study not only learning-induced or experience-dependent neural changes, but also identify what brain networks characterize individual differences in learning and representation. Although progress has been made with this approach to study language learning and representation at the single-word level (see Li & Grant, 2016; Yang, Gates, Molenaar, & Li, 2015 for applying this method to L2 word learning), how this approach can provide significant insights into the understanding of text comprehension in native and second languages remains unclear.

This article takes the significant gaps (lack of understanding text-level knowledge structure, individual difference, and neural network patterns) as a starting point for presenting an integrative perspective on reading comprehension. Perhaps a unifying force or a key to this effort is the study of malleable individual difference, especially the mental lexicon with its pieces of knowledge structures, through which we hope to understand how mental representation of text (the KS) is derived successfully or unsuccessfully after reading.

2. Knowledge structure mechanisms in reading comprehension

2.1. *Modeling knowledge structure in reading comprehension*

A large number of studies have been devoted to computational models of semantic space such as Latent Semantic Analysis (LSA; Landauer, Foltz, & Laham, 1998) and Hyperspace Analogue to Language (HAL; Burgess, 1998). These vector-based models of word meanings measure knowledge representations through the use of co-occurrence statistics across a very large text corpus, and they have been successfully applied in hundreds of studies across a broad range of investigations in highly diverse domains, for example, from predicting reaction time response in adults to identifying tone sequences and classes in whale songs (Kaufman, Green, Seitz, & Burgess, 2012). Note that the text comparisons generated as output for these HAL and LSA approaches can be highly similar: Yan, Li, and Song (2004) reported a correlation of r = 0.98 between HAL and LSA text comparison output. This shows that 'knowledge structure' is a robust measurable phenomenon that manifests an influence on cognitive performances, even in other species. So part of learning is acquiring such lexical cognitive structures.

The *ALA-Reader* measures of knowledge structure as mentioned in Section 1.2 differ from LSA and HAL or other *global-scale* semantic space models, but it can lead to similar or better measures of *local-topic* knowledge structure in L1 and L2 reading comprehension. To illustrate, Koul, Clariana, and Salehi (2005) asked students to work in pairs in class to research the topic "the structure and function of the human heart and circulatory system", then each pair constructed a concept map of this topic and printed it out. Later, each student was asked to write a 250-word essay on this topic using the writing prompt of an LSA demonstration web-site (http://lsa.colorado.edu/). These essays were then scored by 12 pairs of human raters, and by LSA and *ALA-Reader*, respectively. The

LSA and *ALA-Reader* essay scores were compared by Pearson correlation to the total combined score averaged from the scores of the 12 pairs of raters, for each essay. The correlations obtained were: LSA to total, r = 0.62, *ALA-Reader* to total, r = 0.71, LSA to *ALA-Reader*, r = 0.57. *ALA-Reader* was better than LSA for this LSA writing prompt, explaining 12% more variance in the combined score (e.g., 50% vs. 38%), and LSA and *ALA-Reader* were only moderately related (see Koul et al., 2005 for further details). In another study, Su and Hung (2010) asked 5th and 6th grade students (n = 416) in Taiwan to read a Chinese expository text about honey bees and then write a summary of about 300 Chinese characters long. These Chinese language summaries were scored with both *LSA* and *ALA-Reader* and these derived essay scores were compared to human rater scores. The Pearson correlations obtained were LSA to raters, r = 0.56 and *ALA-Reader* to raters, r = 0.63. As above, *ALA-Reader* performed better than LSA for this "bee" writing prompt, explaining 8% more of the variance in the rater scores (e.g., 40% vs. 31%).

How do local-topic approaches measure the KS? *ALA-Reader* uses text pattern-matching of n number of pre-selected key concepts/word stems to generate an *n x n* array of the sequential occurrences of these words/stems in a text (e.g., in lesson texts, in students' essays). The *ALA-Reader* approach has been modified and improved over time through a number of monolingual English investigations in order to improve its concurrent validity, and has also been recently applied in a monolingual Dutch setting (Fesel et al., 2015) and in bilingual settings including Dutch-English (Mun, 2015), Chinese-English (Tang & Clariana, 2017), and Korean-English (Kim & Clariana, 2015, 2017).

The *ALA-Reader* approach for eliciting, representing, and comparing knowledge structure (KS) as Pathfinder networks (Schvaneveldt, Durso, & Dearholt, 1989) provides explicit representations of KS, rather than implicit (hidden) such as HAL or LSA vectors. Pathfinder analysis was designed as a psychometric scaling approach based on graph theory that utilizes a triangle equivalence algorithm to determine shortest paths in sets of association data in order to reveal underlying organization or structure of the data (Schvaneveldt et al., 1989). The Pathfinder analysis algorithm is a data reduction approach that uses only the strongest associations in the array, and so it aligns well with the term co-occurrence approach employed by *ALA- Reader*. For this and other reasons, *ALA-Reader* was designed specifically to output file formats that are directly readable by Pathfinder Knowledge Network Organizing Tool (KNOT; http://interlinkinc.net/Download.html).

2.2. Role of L2 proficiency and L1 structure in L2 reading comprehension

Reading ability and language proficiency are separate but related cognitive phenomena; for example, low proficient bilinguals may be highly competent readers in L1 but not in L2. Cognitive studies of reading indicate that less proficient readers approach an expository text using a "default/list strategy" (Ray & Meyer, 2011) while proficient adult readers implicitly or explicitly seek and attain structure from that text. We would primarily attribute this reading strategy difference to the richness of the local lexical structure that accrues through experience. So a pattern of linear KS from reading an expository text would be likely attained for children due to their total language exposure (Fesel et al., 2015) and also possibly for low proficient bilinguals as well when reading in L2 but not necessarily when reading in their L1, as their L1 and L2 KS richness and complexity should be quite different due to past experiences.

General measures of L2 vocabulary are important in reading studies, but measures of local-topic KS provide a more precise way to determine the extent and quality of the lexicon structure in any specific task-driven mental space. Measures of KS represented as network graphs commonly show that the key terms/concept words in a text are more central than others (e.g., high degree nodes that have the most links to other terms) except for texts describing unusually linear thinking such as procedures, directions, and flows. The central terms are most important for setting the relational meta-structure of the text passage. In fact, each individual text has a unique situational local structure that can range from more sequential/linear to more relational to hyper clustered depending on the nature of the content. Examining readers' post-reading KS and comparing it to the local structure of the text is a direct way to know if a reader has acquired the structure of the text as intended by the author, and in a bilingual setting, the influence of the L2 text on both L1 KS and L2 KS can also be considered.

Some common KS network forms have been quantified by Clariana, Rysavy, and Taricani (2015) using Freeman's graph centrality metric with small sparse networks (nodes < 25), a graph-theoretical metric which ranges from zero to one. This range of graph centrality values has been qualitatively characterized into a conceptual typology: 0–0.2 linear form, goal-oriented, 0.2–0.4

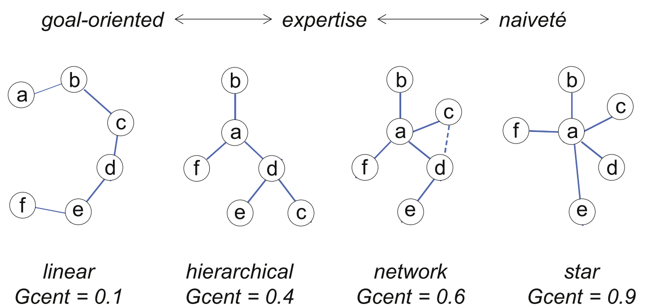

Fig. 1. Four different networks indicating different levels of comprehension (from Clariana, Draper, & Land, 2011).

hierarchical form, expertise, 0.4–0.6 network form, also expertise, and 0.6–1.0 star form, naiveté (see Fig. 1 for an example). The Appendix also provides an example text along with its network structure (see Follmer, Fang, Clariana, Meyer, & Li, 2018 for details). No one typology is 'best', but rather, specific forms are best for specific tasks. Regarding comprehension of expository text, posttest performance on traditional tests should be optimal when the readers' network form matches that of the lesson text.

Such post-reading KS measures can be used in neurocognitive studies in several ways. For example, to classify readers after reading in an MRI scanner as having used a list strategy or a relational strategy in order to determine what patterns of brain activation relate to each reading approach. Further, proposition level KS analysis after reading can point out specific successes and failures that likely occurred while reading the text, and so these can be used to identify brain activation patterns associated with these successes and failures as long as the time sequence of the word display is known. Also, post-reading measures of L1 and L2 KS could help interpret L1 and L2 fMRI activation pattern similarities and differences between L1 and L2, the activation patterns observed may then be attributed due in some part to text coherence features rather than just general L1/L2 language effects or reading comprehension ability. To show how this could work, the next section provides several investigations of KS in L1/L2 settings.

2.3. Knowledge structure measures in L1 and L2

A study by Mun (2015) considered the influence of L2 reading and post-reading production tasks on L1 and L2 KS and on posttest comprehension. Dutch undergraduate students who were highly proficient in English read an English 722-word expository text, the TESOL passage "*The Cave of Lascaux*" and then were randomly assigned to one of four groups: (1) Sort(E) – completed a concept sorting task in L2 (English), (2) Sort(D) – completed a concept sorting task in L1 (Dutch), (3) Write(E) – wrote a summary of the text in L2, and (4) Write(D) – wrote a summary of the text in L1, and finally all readers completed the associated English TESOL 9-item multiple-choice reading comprehension posttest. The observed posttest mean order was: Write(D) 8.6 (significant) > Write(E) 7.9 > Sort(D) 7.4 > Sort(E) 7.1; the post reading tasks influenced posttest performance downstream, language used was not significant but writing > sorting (significant). Further the KS elicited by writing was quite different for L1 and L2. The average graph centrality mean for the Write(D) group was 0.27 (SD = 0.19) while for the Write(E) group was 0.51 (SD = 0.15), indicating that the average networks of Write(D) group had a more linear structure, whereas those of Write(E) group had a relational network structure. Why did the Write(D) attain the greatest posttest score and also the most linear KS form? Write(D) is a translation task (L2 to L1) that may allow the more richly structured L1 to support the L2 posttest performance; and the Dutch language itself may be more "linear"; the graph centrality of the "Cave" lesson text in English is 0.44 and the graph centrality of a professional translation of this text into Dutch is 0.19 (Mun, 2015, p. 22); based on this set of data, we conducted a follow-up study that used 10 texts and their translations, and observed the same increased linearity for Dutch relative to English in all 10 texts, although the difference was smaller than observed here.

A study by Kim and Clariana (2015) also considered the influence of L2 reading and post-reading production tasks on L1 and L2 KS, and also on posttest comprehension. Korean undergraduate students who had low English proficiency read the same expository text, the TESOL passage "*The Cave of Lascaux*" and were randomly assigned to one of two groups: (1) a *Directed writing task* (English only) that asked the participants to work only in English (read in their L2, R - read) in order to create a concept map of the text (M - map), write a summary of the text (W - write), and then create a second concept map before completing the multiple-choice comprehension posttest or (2) a *Translated writing task* (Korean and English) that asked the participants to create a concept map of the text in Korean, write a summary of the text in Korean, draw a second concept map in Korean, write a summary of the text in English, create a concept map in English before completing the multiple-choice comprehension posttest, schematically as:

- *Directed Writing group*: R(E) → M(E) - - - - - - - - - - - - - → W(E) → M(E) → posttest
- *Translated Writing group*: R(E) → M(K) → W(K) → M(K) → W(E) → M(E) → posttest

KS was calculated at each task for these concept maps and essays using the approaches described by Clariana (2010b), as discussed above. Data analysis consisted of (a) the extent and importance of the terms used in the post-reading tasks, (b) individuals' own pre-to-post map similarity, (c) individuals' pre and post map similarity to the expert's map, (d) comprehension posttest correlation with individuals' pre and post map similarity to the expert's map, (e) essay graph centrality means, and (f) comprehension posttest correlation with graph centrality values.

First using simple counting analysis, the extent and importance of the terms were strikingly different even at the first mapping task after the reading. Participants in the *Directed Writing* group who read and then mapped in English had 14.4 terms on average in their maps and these terms had 32% agreement with the expert's terms compared to those in the *Translated Writing* group who read in English and then mapped in Korean with 19.9 terms and 58% agreement with the expert. This substantive advantage for quantity and quality of terms for Korean mapping immediate after reading in English carried forward through all of the post-reading tasks. Regarding comprehension posttest performance, the *Translated Writing* group mean of .84 was significantly greater that the *Directed Writing* group mean of .62, pooled standard deviation of 0.16 (Cohen effect size of 1.4).

But going deeper, the KS measures allowed for comparison to an expert referent and for student-to-student comparison as well (e.g., peer knowledge convergence). The KS form quality measured as term distance data in the initial Korean maps were more like the expert's map than those of the initial English maps, *Fisher z* = .29 versus 0.67. This initial KS form quality for the Korean maps improved across each succeeding task, with a final Korean map form quality of *Fisher z* = 0.74 compared to the final English map form quality of *Fisher z* = 0.40. The KS form recalculated as graph centrality also showed distinct differences for the *Directed* versus *Translated Writing* groups, with the English-only tasks showing averaged *linear structure* graph centrality values of 0.23 for the initial map (E) and 0.34 for the final map (E), compared to the English-plus-Korean tasks that show *relational structure* graph centrality values of .51 for the initial map (K) and 0.48 for the final map (E). The relatively large graph centrality values for the English-plus-Korean Translated writing group may be partially or substantially due to KS L1 → L2 asymmetry (Keatley, Spinks, & De Gelder, 1994) where the richly complex Korean initial map KS influences the English post map KS.

Regarding peer-peer knowledge convergence, the *Translated Writing* group members' maps converged more with each other's maps and with the expert map (average overlap to each other is 66% and to the expert is 40%) relative to the *Directed Writing* group members' maps (average overlap to each other is 32% and to the expert is 14%). This shows that the *Translated Writing* group's post maps were much more homogenous (i.e., reflecting a very similar KS) while the *Directed Writing* group post maps, although still alike, were relatively more idiosyncratic. A follow-up study (Kim & Clariana, 2017) further validated and extended these findings, but used different treatment conditions to separate out the individual effects of mapping and writing.

So the local-topic KS of L1 and of L2 likely differs, but L1 KS positively influences L2 KS when the post reading task requires L1-L2 interaction. We hypothesize that during reading in both L1 and L2 (and especially in L2), "gaps" in the individual's L2 KS (i.e., lexicon) require recruitment of cognitive resources to bridge or "patch" the developing situation model. The larger L1 chunks of KS can be called upon to support the sparse and less well-structured L2 KS. When this happens during reading, a neurocognitive signature should be apparent in the fMRI patterns, especially the influence during reading of small versus large pieces of local-topic KS on limited working memory. Seven big L1 pieces (plus or minus 2) can bridge better than seven small L2 pieces. So how does the use of or reliance on cognitive resources such as working memory impact the reading of text? In the next section, we discuss specifically the role of working memory on reading comprehension, as there has been a significant amount of work that demonstrates the relationship between the two in monolingual settings.

3. Role of working memory

While the relationship between executive function and language learning has been an area of intense research interest (see, e.g., Baddeley, 2003a; Dörnyei, 2005; Linck & Weiss, 2011 for reviews), this relationship in the context of reading comprehension, particularly reading of text in the reader's L2, has not been well understood. In this section, we focus on one specific type of executive function, which is working memory, given its prominent role in reading comprehension in the literature. We need to isolate the impact that working memory has on the neurocognitive processes and mechanisms underlying second language reading, for example, by accounting for the reader's L2 proficiency or competence. Reading comprehension is an excellent domain for us to examine the role of working memory and individual differences, because when reading a text, the reader needs to search for the critical concepts/words/terms, make semantic links between them, integrate the words into a coherent and structured mental representation, all of which requires the use of working memory and cognitive resource allocation in general. While paying special attention to the key concepts, the reader also needs to inhibit irrelevant information or less relevant words or concepts. We continuously use our cognitive resources to monitor, update, and otherwise switch attention successively at different points in the text. For this reason, any individual differences in reading comprehension might reflect the differences in working memory, giving working memory a central role in studies of reading.

3.1. Role of working memory in L1 reading comprehension

Previous research has indicated that increased working memory abilities are associated with better language learning and processing abilities. Specifically, greater working memory facilitates the learning of novel picture–object associations and word–nonword associations, resulting in larger vocabulary, better syntactic comprehension, and overall better L2 oral fluency (see Baddeley, 2003b; Miyake & Friedman, 1998; O'Brien, Segalowitz, Freed, & Collentine, 2007). Within the working memory model of Baddeley and Hitch (1974), the central executive control system could involve several domain-general components, including updating of information in light of new stimuli, shifting between tasks, and inhibiting habitual responses or irrelevant information. The more language-related component of the working memory system is the phonological loop or phonological working memory, which involves articulatory rehearsal and phonological store mechanisms. Phonological working memory is crucial for language acquisition, L1 and L2 alike, because it serves to recursively hold in memory novel phonological units temporarily while more stable long-term representations are being formed (Baddeley et al., 1998). It has been found that adults who have better phonological working memory are better L2 learners in vocabulary and grammatical processing (Baddeley, 2003b; Miyake & Friedman, 1998). More recently, it has been shown that the episodic buffer, a component that provides a bridge between working memory and long-term memory, could also play a significant role in L1 and L2 vocabulary learning and word recognition, given its role in binding information from different modalities (Wang, Allen, Lee, & Hsieh, 2015; Wang, Allen, Fang, & Li, 2017). Episodic buffer also plays a significant role in higher-level reading processes since episodic memory maintains the incidental order of a series of events that comprise a specific experience; in this case the events are the words that are actually attended to during reading, and the episode consists of the linear/sequential word order in the text modified by regressions that will alter that episode sequence highlighted by each word's salience to the learner.

A large body of research has shown that reading comprehension abilities are associated with working memory capacity in both normal and disordered populations (e.g., Just & Carpenter, 1992; Swanson, 1999 for reviews). A growing number of reading comprehension studies also indicate that working memory could be an ideal candidate for understanding how cognitive characteristics of the reader interact with characteristics of text or text properties (see Meyer, 2003 for review of key variables in such interactions). For example, in the Landscape Model of reading (Van den Broek, 2010; Yeari & van den Broek, 2011), working memory is crucial for establishing the link between concepts/elements that are related and co-activated, for integrating prior knowledge with the new concepts being read, and for bridging inferences and updating the situation model. In the RSF model of multiple interactive components of reading (Perfetti & Stafura, 2014; see discussion in Section 1.1), the 'word-to-text integration' system is separate from the 'word identification' system, both of which involve working memory for processes such as phonological decoding and semantic retrieval. Readers who are low in working memory will have difficulty in making simple connections across key elements in the text (e.g., pronominal referential relations, spatial relations for brain anatomy texts, or temporal relations for chronological events in history texts), or they will fail in identifying correct causal/logical relations across concepts (e.g., 'meteor explosion' and 'species extinction' in a text describing environmental impact). Readers who are high in working memory (along with other attentional control abilities) may be more at ease in establishing such referential and causal relations, thereby more effectively organizing the semantic network of concepts into a structured mental representation.

Note that expository texts, as compared with narrative texts, may place higher working memory load on the reader, given the lack of story plots with characters, events, and settings to bind the memory episode. In such cases reader characteristics and text characteristics will likely interact, showing a stronger effect of working memory in reading expository than narrative texts. Indeed, Eason et al. (2012) showed that understanding of expository texts, compared to narrative texts, requires greater cognitive ability in synthesizing information across larger chunks of text for mental organization (i.e., abilities to organize information and make inference subsequently), and deficits in such skills may cause poorer reading comprehension, especially among young readers. Although not specifically testing working memory, Eason et al. interpreted the role of cognitive ability (planning/organizing information and drawing inferences) as critical for forming a coherent mental representation of text by facilitating the integration of text elements across distance (see also Miller, Davis, Gilbert, & Cho, 2014), which is consistent with the role of working memory. Sesma, Mahone, Levine, Eason, and Cutting (2009) also demonstrated that in a group of 9-15-year-old children with reading comprehension deficit, executive functioning (including both working memory and planning) makes a significant contribution to reading comprehension (but not single word reading), accounting for 63% of the variance on top of other important variables such as attention, decoding skills, fluency, and vocabulary.

3.2. Role of working memory in L2 reading comprehension

Given the above picture, how does working memory play a role in the reading comprehension of text in one's second language? Larger local-topic KS pieces in long-term memory with concomitant automaticity allow for top-down processing, while smaller or no KS pieces can only use bottom-up processing, as previous work suggests. So the first problem is that L2 readers may have more difficulty with the word-identification system (see RSF discussion earlier) and so are slower at bottom-up processes from phonological decoding to semantic retrieval, as compared with L1 native readers. They may also show reduced chunking ability, maintaining a smaller amount of information in working memory as compared with that in their L1 due to a more poorly organized or less robust representation of word forms or phonological units. This suggests that bilingual readers must recruit more cognitive resources and especially working memory in handling the flow of text for successful reading comprehension. In an earlier study, Harrington and Sawyer (1992) tested a group of Japanese learners of English who read short English sentences in groups of 2–5 sentences in a set, and then performed a reading span test (Daneman & Carpenter, 1980), along with other working memory tests such as digit span and word span tests. Standardized reading ability scores from Test of English as a Foreign Language (TOEFL) were correlated with L2 readers' reading span results (but not with digit or word span), suggesting a positive relationship between working memory and reading comprehension in the L2. Note that this study tested working memory span only in the L2, and it is unclear whether working memory tested in L1 would also correlate with reading ability scores. Additionally, it is unknown whether L2 working memory span relates to the specific components of reading comprehension such as word-to-text integration (bottom-up) or inference or situation model building (top-down) processes, as the study used only standardized reading scores (i.e., TOEFL scores) as a measure of reading comprehension.

In another study, Walter (2004) examined French learners of English at two different levels of proficiency in the L2, the lower-intermediate group and the upper-intermediate group. Unlike the Harrington and Sawyer study, Walter asked participants to read short stories of English text and then to complete a summary test of those texts. The two groups of participants showed different levels of comprehension in both L1 and L2, although the difference in L2 was greater than in L1 (much worse in L2 for the low-intermediate proficiency group). Thus, the level of L2 proficiency directly impacted L2 reading comprehension, which is not surprising. More important, the lower-intermediate proficiency group showed difficulty with referential cohesion, not in their L1 French, but in L2 English, mainly for long-distance pronoun references. This suggests that the lower proficiency learners have trouble building a structural coherence of the text by using the correct referential devices. In general, these data suggest that low-proficiency learners, as compared with high-proficiency learners, cannot successfully transfer their L1 reading skills to L2 reading comprehension (but see Clariana et al., 2015 discussed above), because the relatively less richly structured L2 requires greater working memory to bridge text coherence gaps. Interestingly, working memory and L2 proficiency show an interaction, in that enhanced working memory helps the lower-intermediate proficiency group more than the upper-intermediate group for reading comprehension. This interaction pattern may suggest that the lower proficiency learners may need to rely extensively on attentional/executive control while performing the bottom-up L2 analyses, and those who have larger working memory can more effectively handle the two tasks well. This is also consistent with the neural evidence that the prefrontal cortex (especially the dorsolateral prefrontal cortex or dlPFC) becomes particularly active when people perform dual tasks that tax working memory heavily (D'Esposito et al., 1995).

There has already been abundant work delineating the neural substrates of various executive, verbal, and visuospatial components of working memory. This literature has implicated a network of critical regions in the left and right dlPFC (executive processes including dual-tasking and top-down control of attention), ventrolateral PFC (phonological loop), anterior cingulate cortex (ACC, attention, monitoring, and conflict resolution), and the left temporo-parietal junction (sensorimotor integration) (see Osaka, Logie, & D'Esposito, 2007 for reviews). Simultaneously, there has also been a sizeable amount of neuroimaging work that underscores the importance of working memory and attentional control in the cortical and subcortical regions of the brain for L2 functions (see Abutalebi & Green, 2007; Li, Legault, & Litcofsky, 2014 for reviews). Abutalebi (2008) and Abutalebi and Green (2007) laid out an interconnected network that relates bilingual language control to working memory and inhibitory control. Specifically, the PFC and the ACC are engaged when the bilingual speaker inhibits the unwanted language, because items from both languages may be mentally active. The inferior parietal cortex also plays a significant role, because of its importance in lexical representation, phonological storage, and semantic integration. Typically, in a bilingual situation when the speaker or listener is speaking, reading, or listening in L2, when an L2 coherence gap occurs, added systems are recruited to bridge the gap, especially the dominant language lexicon (usually the L1), which requires more active involvement of the cognitive control system to inhibit L1 intrusions. Finally, the basal ganglia, particularly the caudate and putamen, could play a role to mediate the selection and articulation of L1 and L2 words while suppressing the words not in use (see, e.g., Crinion et al., 2006).

The basal ganglia, a subcortical structure, may also form an integrated neural circuitry with the PFC to modulate language control. In our own work (e.g., Yang & Li, 2012), we have found significant three-way correlations between language learning performance, cortical activation, and working memory capacity. Interestingly, individual differences in working memory, as measured by the letter–number sequencing task (Wechsler, 1997), correlated with performance accuracy for the explicit learning group, but not for the implicit learning group. In addition, the strength of connection between the basal ganglia and the prefrontal cortex may also be task dependent. This cortical-subcortical neural network has been further studied in some recent work by Stocco, Yamasaki, Natalenko, and Prat (2014), who proposed the conditional routing model (see also Stocco, Lebiere, & Anderson, 2010), according to which the frontal-striatal loop serves an important function of working memory for control and attention. The basal ganglia can both alter the number and the type of information directed to the PFC that has been traditionally considered the hub of working memory processing. Specifically, this model hypothesizes that the basal ganglia plays a key role in 'gating', that is, flexibly selecting the relevant information (e.g., propositions) and routing it to the PFC for processing. This suggests that we should study how cortico-cortical and cortical-striatal networks are configured in the face of competing cognitive and linguistic demands (reading in the L1 vs. reading in the L2 that involves different levels of attention, task switching, and conflict resolution). Individuals with lower working memory may have less flexible gating mechanisms as compared with those with higher working memory capacity, and as a result, unsuccessfully route the important information to the PFC during reading, or fail to inhibit irrelevant information from one's native language while reading in the L2.

The neural signatures of individual differences as revealed by working memory are interesting pathways to a deeper understanding of why and how L2 learners can successfully read in a second language. The studies discussed so far seem to suggest that less experience and proficiency with an L2 will lead to increased activation in cognitive control and therefore the reader who has high working memory has a better chance to allocate needed attention while performing the linguistic task. A slightly different scenario in which increased L2 proficiency may lead to a more focused pattern of activation in cognitive control areas is also possible, because the less proficient L2 learners need to recruit more cognitive resources and hence a more widespread network (e.g., in the right hemisphere) to handle the more cognitive demanding task of reading in the L2 (e.g., Prat & Just, 2011). The dynamic changes involved in the use of cognitive control versus effective language processing were recently identified in a longitudinal fMRI study by Grant, Fang, and Li (2015): L2 Spanish learners showed more engagement of the control system involving the prefrontal regions when their L2 proficiency was low, but an integrated semantic network with the middle temporal gyrus as a hub to connect with frontal and temporal regions when proficiency increased. It is important to note that proficiency and age of acquisition are often confounded in studies and should be carefully distinguished in the future (see Grosjean & Li, 2013; Hernandez & Li, 2007 for reviews), even in late L2 learners there can be islands of high L2 proficiency based on selective L2 exposure such as in graduate students with expansive L2 domain-specific knowledge structures (i.e., domain-specific lexicon) but who maintain generally low L2 proficiency outside of the domain content. Thus, it is important to understand the neural mechanisms of working memory and its interaction with variables such as age and proficiency that give rise to individual differences in reading comprehension. A final important question is whether the correlation between working memory and reading comprehension implies a causal relationship, such that the training of working memory can have a positive effect on reading behavior in both L1 and L2. This seems promising given recent evidence from several studies in this direction (see Prat, Seo, & Yamasaki, 2015 for discussion).

4. A neurocognitive perspective

4.1. Neurocognitive processes in L1 reading comprehension

Given the important role that reading plays and the intensity with which our daily lives are involved in reading, it is amply clear that reading impacts the brain, both in functional and neuroanatomical ways (see e.g., Carreiras et al., 2009; Dehaene et al., 2010). The past decade has also seen growing interest in the neurocognitive mechanisms of reading not only at the single-word level but also at the sentence and discourse levels. With respect to the neural processes of text reading comprehension, Mason and Just (2006) proposed that there exist five distinct networks in the framework of Parallel Networks of Discourse. These include the coarse semantic processing network in the right middle and superior temporal cortex, the coherence monitoring network in the bilateral dlPFC, the text integration network in the left inferior frontal-anterior temporal lobe, the protagonist's perspective interpreter network in the bilateral medial frontal and posterior parietal lobe, and the spatial imagery network in the bilateral intraparietal sulcus. For example, the dlPFC has been implicated as a key hub for cognitive control, especially working memory (see discussion in Section 3), and it is no wonder that it also serves the role of coherence monitoring in text reading. Of particular interest is the Parallel Networks of Discourse model's emphasis on the role of the right hemisphere, which has not traditionally been highly valued in word-level language studies (but highlighted by figurative language research). This contrasts with the role of the left hemisphere that may play a more important role in word-level and proposition-level information processing and representation. A number of neuroimaging studies showed that the right hemisphere is additionally activated in the processes of inference drawing (e.g., monitoring the moral of the story), coherence building (establishing anaphoric references), and figurative language processing (understanding metaphor, interpreting idioms, etc.). In a recent study, Schloss and Li (2017) showed that the left vs. the right hemisphere differences based on fMRI activation patterns (e.g., Mitchell et al., 2008) could be predicted by *semantic space models* that highlight fine vs. coarse semantic features (e.g., word-dependence level vs. document-level models, respectively; see also Li, Schloss, & Follmer, 2017).

Reading comprehension is a dynamical process that unfolds quickly in time, and as such, the cortical activations and brain networks are also dynamically evolving. It would be too simplistic to assign the functional role of text reading to just a few brain areas or even a large number of brain areas individually. Rather, the functional specificity is dependent on both the text properties and on the individual reader's cognitive capacity, and most important for the current discussion, on the dynamic configuration and reconfiguration of brain network properties in real time when reading unfolds. For example, other than the dlPFC in coherence monitoring, the dmPFC (dorsomedial prefrontal cortex) is also engaged in building text coherence and drawing bridging inferences. However, dmPFC's role has been less clear when the text to be read is expository rather than narrative (see Swett et al., 2013) – note that most previous imaging work has focused on narrative text or story reading, where the mental states of the reader and of others may be a necessary part of the narrative, while in contrast, theory of mind issues are usually not part of expository text.

Other important cognitive systems may also play a role, as we previously pointed out regarding the dlPFC (for both working memory and coherence monitoring). In addition, the cingulate cortex has been implicated as a critical hub along with the anterior insula in the attention network, and it can become highly activated not only when additional cognitive resources are required, but also when the reader is detecting the shift of a story line or location of characters (Whitney et al., 2009). Breaking a narrative into cogent episodes may be a natural way for the reader to update his or her situation model and to incorporate the new events and characters into the comprehension system as reading unfolds in time; the dlPFC may serve to both close the door to an episode as well as provide the link to the next episode. It is curious that the hippocampus has not surfaced as a key hub for text reading so far, and how hippocampus plays its role in episodic memory, in connection with dlPFC and other areas (e.g., precuneus), is an interesting research question.

Finally, the inferior parietal lobule (IPL), including both the supramarginal gyrus and the angular gyrus, may become engaged when large-scale conceptual and semantic integrations are required, as IPL has been previously found to be a hub in integrating semantic relations across modalities and in building event representation and interpreting pragmatics such as metaphors, ironies, and sarcasms (Binder & Desai, 2011; Yarkoni, Speer, & Zacks, 2008). For example, Yang et al. (2016) showed that the angular gyrus, especially in the right hemisphere, is particularly activated when Chinese idioms are being understood when a significant amount of background of social-cultural-semantic knowledge is involved for interpreting historically rich forms of idioms.

In Fig. 2, we present a quick sketch of the key brain regions that may be involved in reading comprehension, although this figure is meant to be illustrative rather than exhaustive. The critical network typologies and connectivity properties are absent from this figure; to identify the network properties will be a major goal for future research.

4.2. Neurocognitive processes in L2 reading comprehension

How might this picture of brain mechanisms from native language reading studies be applied to reading comprehension in a

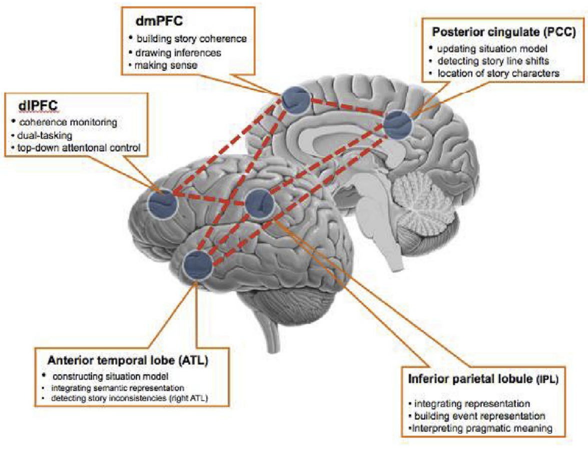

Fig. 2. Key brain structures that support reading comprehension (based mostly on narrative text reading). Dashed lines indicate hypothetical connections. Right-hemisphere homologue areas are not shown for clarity.

second language? Concrete answers to this question are currently unavailable, given the lack of neuroimaging work in this domain. In the absence of specific studies to address this question, we provide some speculative proposals for future research considerations.

First, as discussed above, there exist significant individual differences in reading performance that may be related to the reader's cognitive capacity such as working memory that interacts with the extent of the individual's knowledge structure of that topic. There is also emerging neuroimaging evidence that brain response patterns may provide signatures of individual reading variability, especially through cognitive control and working memory (see Osaka & Osaka, 2007; Prat et al., 2015 for reviews). For example, L2 readers whose working memory is high may show neurocognitive patterns that are more similar to native readers in that they will rely less on cognitive resources and will focus more on directly accessing the meaning of the words and sentences from the surrounding context, much like an L1 reader incidentally learns new words while reading. This means that critical cognitive control areas such as the dlPFC and ACC may not activate as strongly as in L2 readers whose working memory is low. For the latter group, the reader's language processing network will continually interact with the cognitive control network, because the reader needs to devote additional resources to keep track of the relationships between lexical items and make inferences across sentences. It is also possible that low working memory readers will activate additional cortical regions in the right hemisphere especially the right MTG, given the involvement of the right brain regions in bridging inferences and integrating text into coherent semantic representations (Mason & Just, 2006).

Second, reader properties such as working memory and cognitive control will likely interact with the level of proficiency of the reader in the L2. This assumption is based on Grant et al. (2015), as mentioned earlier, in which connectivity patterns of bilingual English-Spanish speakers changed when the L2 proficiency increased. Specifically, key language regions such as the IFG and the MTG, areas responsible for lexical semantic selection, activation and integration, became more strongly connected with increased proficiency (possibly as a direct result of the larger extent and quality of the L2 KS lexicon), whereas connections between key areas for cognitive control such as MFG and the caudate nucleus, became weakened. This pattern indicates that low-proficiency L2 learners evoke the cognitive control network more strongly, whereas higher-proficiency L2 learners use the semantic network more efficiently (and effortlessly) for L2 meaning access and retrieval. This is indicative of a shift from paying attention to control (more effortful, non-linguistic processing) to paying attention to meaning access (more automatic, linguistic processing) in cases of lexical semantic competition across language (e.g., the meaning of 'pie' in English vs. that in Spanish). While the Grant et al. study did not separate learners at the high working memory vs. low working memory levels, it is reasonable to suggest that there might be an interaction between working memory capacity and proficiency (e.g., as increase in L2 topic-related KS quality and extent), such that the effects of proficiency might be more transparent or pronounced in the low working memory group, which could hold not only for word-level processing but also for sentence-level and text-level reading.

Third, high-proficiency, successful L2 readers may approximate the brain network patterns of the L1 readers in activating connections between the visual word form area (VWFA) for visual word information processing, the IPL for lexical/phonological and semantic mapping, and the other key semantic selection and retrieval regions such as the IFG and MTG. By contrast, the low-proficiency or poor L2 readers using a bottom-up word-by-word reading strategy may show decreased activation in the visual, lexical, and semantic processing regions, and instead activate a more top-down attention and control process using the prefrontal cortex especially the dlPFC as a hub. This would be consistent with findings from our L2 studies as reviewed above (Grant et al., 2015). In addition, the brain network responsible for making inferences such as the dmPFC, the TPJ (temporo-parietal junction), and the bilateral IPL may not become activated since the reader may be more focused on bottom-up word-level processing rather than making connections and integrating between sentences in service of building up the situation model.

In a recent study of text reading in native speakers of Chinese, we have identified a network of dorsal and ventral visual systems involved in text reading (Zhou et al., 2016). In particular, word-level information may automatically trigger VWFA in the ventral visual system, whereas word-to-text integration may involve MFG and IPS (intraparietal sulcus) modulations in the dorsal system, because the latter involves the use of world knowledge for causal inference. Our study showed that these dorsal and ventral regions are connected to form an integrated network during text reading. Specifically, the strength of connection between regions in the dorsal system (MFG-IPS, but not the ventral VWFA-MFG) are correlated with the reader's fluency of reading scores when the reader is in a resting state (based on data from resting-state fMRI), suggesting that text reading may tap into the frontal-parietal regions more strongly than in the ventral systems. However, these data were all from native monolingual speakers, and how this ventral-vs-dorsal pathway picture applies to L2 readers is yet unknown. A key future direction to study the efficiency and proficiency in L2 text comprehension will be the examination of the brain network interactions between the frontal, posterior temporal, and parietal regions in both the dorsal and ventral systems. Investigations of the brain connectivity patterns, and especially how the top-down versus bottom-up processes interact in text reading, will no doubt lead to new insights in this domain.

5. Conclusions

In this article, we aimed at providing an overview of some of the key issues in the study of reading comprehension in first and second language from a neurocognitive perspective. Specifically, we discussed approaches toward capturing the knowledge structure that L1 and L2 readers attain after reading, variables that are important in building such knowledge structures (e.g., word-to-text integration, language proficiency, and working memory), and the neurocognitive mechanisms that underlie processes and abilities of reading comprehension in the reader's two languages. The study of reading comprehension in the second language is a relatively new discipline and there are many exciting new issues as well as challenges that face researchers. We hope that this article provides a good starting point for some of these issues to be further pursued in neurocognitive studies, and with new paradigms, advanced techniques, and novel approaches.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jneuroling.2018.03.005.

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